(Luo et al., 2023). More broadly, identifying representative test environments is valuable because selection in those environments can improve the efficiency of screening and strengthen recommendations for similar agro-ecological conditions.

Production optimization should therefore combine species selection with cropping-system adjustment and soil management. Legume-based rotations tend to maintain yields and production stability by improving soil fertility and reducing dependence on external inputs. Long-term evidence from China also shows that legume inclusion can support more stable subsequent crop production and greater resistance and resilience under changing fertilization conditions, indicating that stability benefits are not limited to a single season (Liu et al., 2023). In practical terms, Zhejiang should prioritize legume species with broad adaptation for large-scale promotion, reserve specifically adapted species for matching ecological niches, and integrate legumes into rotations or intercrops where soil quality, resource-use efficiency, and system-level stability can all be improved. Overall, this case-study framework supports a comparative and regionally differentiated interpretation of yield stability among legume crops in Zhejiang. It is most useful for identifying which legumes are broadly stable, which are locally advantageous, and how production can be optimized through ecological matching and diversified cropping systems.

9 Conclusions and Future Perspectives

This study conducted a systematic comparison of yield stability among major legume species cultivated across Zhejiang Province, drawing on multi-year, multi-location data to capture the full spectrum of environmental variability characteristic of the region. The results reveal that soybean and broad bean exhibit relatively high yield stability, with lower coefficients of variation across years and ecological zones, while cowpea and adzuki bean display greater interannual fluctuation. These differences are attributable to a combination of physiological traits, root system architecture, and sensitivity to temperature and precipitation extremes during critical growth stages. A second key finding is that genotype-environment interaction effects are pronounced for all legume species examined, meaning that a variety performing well in one ecological subregion of Zhejiang may underperform in another. The application of multiple stability parameters-including the coefficient of variation, Shukla's stability variance, and AMMI-based stability scores-demonstrated that no single indicator fully captures the complexity of yield stability, and a composite evaluation framework is essential for robust ranking. Taken together, the findings provide an evidence base for tailoring legume variety selection and cropping system design to specific agro-ecological conditions within the province.

Several limitations should be acknowledged. First, the temporal coverage of the yield data, while spanning multiple years, may not fully capture the increasing frequency of extreme weather events associated with ongoing climate change, potentially limiting the predictive value of historical stability estimates. Second, the analysis relied primarily on regional aggregate statistics and published trial records; farm-level heterogeneity in management practices, soil fertility, and pest pressure could not be fully controlled, introducing unquantified variability into the stability comparisons. Third, the study focused on the most widely planted legume species and did not include minor or underutilized legumes that may hold untapped resilience potential. Future research should prioritize several directions. Long-term, standardized field experiments across representative ecological zones of Zhejiang are needed to generate high-resolution, plot-level yield data under controlled management protocols. Integrating crop growth models with climate projection scenarios would allow researchers to simulate yield stability under future warming and altered precipitation patterns, providing forward-looking guidance rather than retrospective description. Additionally, genomic and molecular tools-including marker-assisted selection and genome-wide association studies-should be leveraged to identify quantitative trait loci associated with stability-related traits, accelerating the breeding of climate-resilient legume varieties. Finally, socio-economic dimensions such as farmer adoption behavior, market price volatility, and the profitability of stable versus high-yielding varieties warrant investigation to ensure that agronomic recommendations are economically viable.

The legume industry in Zhejiang Province holds considerable development potential, driven by growing consumer demand for plant-based protein, the ecological benefits of legumes in crop rotation systems, and policy support for